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The Relationship of Muscle Fibre Size to Tenderness of Beef

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ABSTRACT

Steaks were removed from loins of beef carcasses at 1, 3, 6 or 14 days post mortem *for fragmentation index (MFI), Warner–Bratzler Shear Force (SF) and sensory panel tenderness evaluation. Also, after 1 day of storage, samples were removed for histological observations. Greatest improvement in tenderness, SF and MFI occurred within the first 6 days of storage. Sensory panel tenderness was correlated ($P < 0{\cdot}01$) with SF and MFI. Average muscle fibre size was correlated ($P < 0{\cdot}01$) with tenderness and SF at days 1 and 3, but not at days 6 and 14. Evidently, muscle fibre size is important to tenderness prior to post-mortem storage of meat and proteolysis, but becomes less of a factor in tenderness after 6 days of storage.*

INTRODUCTION

Numerous factors have been implicated in the tenderness of beef such as amount and solubility of collagen (Sims & Bailey, 1980), cold-shortening of muscle myofibrils (Pearson, 1986), and post-mortem proteolysis of myofibrillar proteins (Goll *et al.*, 1983; Koohmaraie, 1988; Lanari *et al.*,

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1987). Tuma *et al.* (1962) and Lewis *et al.* (1977) observed correlations between fibre diameter and shear force at 48 h *post mortem* and nonsignificant correlation ($r = -0{\cdot}04$) after 14 days of aging. Berry *et al.* (1971) reported that there was very little relationship between muscle fibre diameter and tenderness when the influence exerted by chronological age was removed. It would appear that the cross-sectional area or diameter of muscle fibres is important at very early post-mortem times, but its importance diminishes with post-mortem storage time as myofibril proteolysis increases.

Increased tenderness associated with post-mortem storage is believed to be primarily due to proteolysis of myofibrillar proteins. The myofibril fragmentation index procedures of Olson & Parrish (1977) and Davis *et al.* (1980), although different in procedure, measure the fragmentation of muscle, and both report their procedures to account for 50% of the tenderness variation within meat from A-maturity cattle. Olson & Parrish (1977) attributed the increase in myofibril fragmentation to the proteolytic activity of the calcium-dependent protease.

The objectives of this study were to investigate the contribution of muscle fibre size to tenderness and examine muscle fibre degradation during post-mortem storage.

MATERIALS AND METHODS

Animals

Charolais steers ($n = 7$) or bulls ($n = 8$) about 15 months of age were slaughtered at the Roman L. Hruska US Meat Animal Research Center abattoir. Cattle had been fed a diet consisting of 25% corn silage, 70% corn and 5% supplement for 4 months prior to slaughter. The time interval from stunning to placing sides in a chill cooler was 50 to 60 min. Cooler temperature was -1 to $+1$ °C. Fans were used to circulate the air within the cooler; however, carcasses had no vigorous air movement on the surfaces. After 1 day *post mortem*, sides were transferred to a holding cooler (2°C).

Temperature decline

Temperature of the *longissimus* muscle (*M. longissimus dorsi*) was taken at 4 or 5 depths of the muscle by inserting a Fluke (Model 8020A) digital multimeter and temperature probe (Model 80 T-150) within the muscle between the 8th and 12th rib at 1, 3, 6, 9, 12 and 20 h *post mortem*. Average value of the 4 or 5 observations were analyzed. Carcasses were ribbed at 1

day *post mortem* between the 12th and 13th ribs. Ribeye area and fat thickness measurements were obtained (USDA, 1976).

Loin and rib samples

At 1 day *post mortem*, a 5-cm section of the *longissimus* muscle was removed between the 11th and 12th rib region. Loin samples between the 13th rib and third lumbar vertebra were removed from carcasses after 1, 3, 6 or 14 days *post mortem* (d1, d3, d6 and d14). At each time *post mortem*, steaks were removed for shear force determination (one steak), sensory evaluation (one steak) and Myofibril Fragmentation Index (MFI).

Sensory tenderness and shear force determination

Steaks were cooked on Farberware 'Open Hearth' broilers (Model 450N, Farberware, Bronx, NY) to an internal temperature endpoint of 70°C, as monitored by iron constantan thermocouples placed in the geometric centre of each steak. After cooking, steaks were tempered for 24 h in a 2 to 3°C cooler. After tempering, six 1·3-cm cores per steak were taken parallel to fibre direction. Each core was sheared on a Warner–Bratzler shear device attached to an Instron Universal testing instrument (Model 1132, Instron Corp., Canton, MA) with microprocessor (Microcon II). The Instron Universal testing instrument was set at a 75% fail criterion and a 5 cm/min crosshead speed. Steaks for sensory evaluation were wrapped in polyethylene-coated freezer paper and frozen at −30°C. At a later date, steaks were tempered (2°C) overnight, cooked as previously described and presented to 6 to 8 trained sensory panelists. Panelists evaluated steaks for tenderness (1 = extremely tough; 8 = extremely tender) according to AMSA (1978) procedures.

Myofibril fragmentation index

Three samples were removed per carcass at each storage period, from the medial, centre and lateral locations within the *longissimus* muscle of one fresh steak. Samples were prepared and analyzed according to the procedures of Culler *et al.* (1978). This procedure essentially measured the degree of fragmentation of myofibrils.

Fibre types

Fibre-type samples were taken per carcass in the medial, centre and lateral locations of the *longissimus* muscle in the 12th rib region at 1 day *post*

mortem. Samples were wrapped in aluminium foil, frozen in liquid nitrogen, and stored at −70°C. Two serial transverse sections of each muscle sample were cut 10 μm thick using a cryostat, and stained for alkali-stable ATPase (Guth & Samaha, 1970) and succinate dehydrogenase activity (Troyer, 1980). Sections were later photographed and enlarged (× 195). A group of 100 or more fibres per sample were counted and classified as red, intermediate or white based on staining intensity. The cross-sectional areas of 25 fibres of each type were then determined using a particle size analyzer. Muscle fibre characteristics are expressed as: average fibre size (the average size of all three fibre types divided by 3), average fibre size proportionately based (the average fibre size after adjusting for the percentages of the three fibre types), and percent white fibre area (the percent muscle area occupied by white muscle fibres calculated from percentages and cross-sectional areas).

Statistical analyses

Data were analyzed by least-squares analysis of variance (SAS, 1985). A split-plot model was used, and included fixed effects for animal gender (whole plot), animal within gender, time *post mortem* (split plot) and gender by time. Animal gender was not an important source of variation for traits reported and was omitted from the discussion. Correlations were computed among dependent variables.

RESULTS AND DISCUSSION

Mean values, and the range of MFI, shear force and sensory tenderness ratings at different post-mortem times, are reported in Table 1. The most dramatic improvement in tenderness, as assessed by either shear-force values or sensory tenderness ratings, occurred in the first 6 days *post mortem*. In fact, shear-force values would tend to suggest that most of the tenderness improvement occurs in the first 6 days of post-mortem storage whereas an additional 8 days showed only marginal improvement. An examination of individual samples showed that steaks from some animals were very tender by 3 days *post mortem* and remained tender for the additional 11 days, whereas steaks from animals that were tough at days 3 and 6 of post-mortem storage continued to decline in shear-force values throughout the 14 days of storage.

The MFI values (Table 1) showed their largest increase in the first 3–6 days of post-mortem storage. The MFI is a procedure which measures the degree

TABLE 1
Means, Standard Deviations and Ranges of Data

Trait	*Mean*	*SD*	*Minimum*	*Maximum*
Hot carcass weight, kg	374·8	41·5	321·6	445·4
Longissimus area, cm^2	90·1	8·4	74·2	107·7
Adjusted fat thickness, cm	0·69	0·28	0·25	1·40
Fibre type				
Average fibre size,[a] μm^2	3 579·1	340·4	2 980·4	4 267·7
Average fibre size,[b] μm^2 (proportionate basis)	3 893·2	381·4	3 298·2	4 747·2
Myofibril fragmentation index				
d1[h]	49·7[d]	13·3	23·7	67·3
d3	55·4[d]	11·9	30·9	69·7
d6	71·2[e]	10·2	51·0	84·2
d14	72·4[e]	17·3	44·3	96·7
Shear force, kg				
d1	7·71[d]	1·35	5·99	11·07
d3	6·20[e]	1·17	4·30	8·05
d6	4·61[f]	1·02	3·12	7·09
d14	3·89[f]	1·10	2·80	6·97
Sensory tenderness[c]				
d1	4·29[d]	0·42	3·50	5·12
d3	4·80[e]	0·37	4·29	5·50
d6	5·11[e,f]	0·56	4·17	6·12
d14	5·38[f,g]	0·49	4·58	6·25

[a] Average fibre size (cross-sectional areas of red, intermediate and white fibres divided by 3).
[b] Average fibre size adjusted for percentage of red, intermediate and white fibres.
[c] Sensory tenderness (extremely tough = 1 to extremely tender = 8).
[d,e,f,g] Means with different superscripts among days (d) within a trait differ ($P < 0·01$).
[h] Day 1 = d1, day 3 = d3, day 6 = d6, and day 14 = d14.

of fragmentation of myofibrils caused by proteolysis (Olson & Parrish, 1977). These data suggest that post-mortem improvements in tenderness are due to proteolysis and that the majority of proteolysis is completed by 6 days of post-mortem storage.

Mean values for temperature decline and correlation coefficients with ribeye area or fat thickness are given in Table 2. Researchers have suggested that temperature decline *post mortem* has a dramatic effect on ultimate tenderness because of the effect of temperature on cold-shortening of fibres or the temperature inhibition of proteolysis (Smith *et al.*, 1976; Lochner *et al.*, 1980). These same researchers have often attributed fat over the *longissimus* as an insulator of the muscle, thereby preventing rapid

TABLE 2
Mean Values for Temperature Decline and Correlation Coefficients for Temperature with Ribeye Area or Fat Thickness

Post-mortem hours	*Temperature*				*Correlation coefficients*	
	$\bar{x}^a$	*SD*	*Min*	*Max*	*Ribeye area*	*Adjusted fat thickness*
1	34·0	0·6	33·0	35·2	−0·39	−0·11
3	29·0	1·7	25·9	31·5	0·39	−0·36
6	20·3	1·4	17·8	23·1	0·06	−0·12
9	14·7	1·3	12·5	17·3	0·64*	0·30
12	10·9	1·6	7·6	12·8	0·47	0·46
20	3·5	0·9	1·8	5·0	0·54*	0·49

* $P < 0·05$.
[a] Means among post-mortem periods (h) differ ($P < 0·001$).

TABLE 3
Correlation Coefficients Between Shear-Force and Myofibril Fragmentation Index Values or Sensory Tenderness Ratings

Post-mortem days	*Sensory tenderness*					*Myofibril fragmentation index (MFI)*				
	d1	*d3*	*d6*	*d14*	*Overall*	*d1*	*d3*	*d6*	*d14*	*Overall*
Shear force										
d1	−0·62*					−0·63*				
d3		−0·79**					−0·62*			
d6			−0·87**					−0·49		
d14				−0·69**					−0·18	
Overall					−0·85**					−0·69**
MFI										
d1	0·56*									
d3		0·59*								
d6			0·51*							
d14				−0·31						
Overall					0·52*					

* $P < 0·05$.
** $P < 0·01$.

TABLE 4
Correlation Coefficients Between Measures of Tenderness and Muscle Fibre Characteristics

Tenderness measurements	*Muscle fibre characteristics*		
	Average fibre size	*Average fibre size, proportionally based*	*Percent white fibre area*
Shear force			
d1	0·53*	0·66**	0·60*
d3	0·67**	0·78**	0·46
d6	0·34	0·47	0·54
d14	0·15	0·30	0·41
Sensory tenderness			
d1	−0·35	−0·48	−0·55*
d3	−0·54*	−0·62*	−0·39
d6	−0·22	−0·34	−0·52*
d14	−0·12	−0·22	−0·40
Myofibril fragmentation index			
d1	−0·60*	−0·63*	−0·19
d3	−0·40	−0·49	−0·42
d6	−0·47	−0·55*	−0·37
d14	−0·35	−0·33	0·13

* $P < 0{\cdot}05$.
** $P < 0{\cdot}01$.

temperature decline. Data observed in Table 2 showed that most of the post-mortem temperature decline occurs in the first 9 h. In addition, ribeye area has a greater effect on post-mortem temperature decline than does fat thickness.

Correlation coefficients between shear-force and MFI values and sensory tenderness ratings are shown in Table 3. Sensory tenderness ratings were significantly correlated to shear values at all storage periods. MFI was significantly correlated to shear-force value and sensory tenderness ratings, except after the 14-day storage period where steaks varied little in tenderness. Overall, the MFI appears to be a good indicator of tenderness, and correlation coefficients can be substantially enlarged if steaks are obtained from animals that vary greatly in tenderness.

Correlation coefficients between various measures of tenderness and muscle fibre characteristics are given in Table 4. Average fibre size, and average fibre size proportionally based, were significantly correlated to shear force, sensory tenderness and MFI primarily at early periods of post-mortem aging. These data are in agreement with earlier observations by

Tuma *et al.* (1962) who observed high correlations of fibre size with tenderness within 24 h *post mortem*, but low correlations after 14 days of storage. This could mean that the average fibre size plays a key role in tenderness prior to post-mortem proteolysis. Evidently, post-mortem proteolysis during storage eliminates the effects of fibre size on tenderness observed soon after slaughter.

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